Rainfall Variability over Thailand Related to the El Nino-Southern Oscillation (ENSO)

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Abstract: This study analyzed the monthly rainfall data of the Global Precipitation Climatology Centre (GPCC) over Thailand, covering the period of 1971 to 2010 using the Empirical Orthogonal Function (EOF) technique. The most dominant mode accounts for 21.6% of the total variance. The next part was a study of the relationship with ENSO using smoothed anomalies between the Nino 3.4 index and the principal component time series.It was found that the Nino 3.4 SST index leads the rainfall anomalies by 4 months. This study used ENSO events divided into weak and strong intensity classes. It was based on composites of fourteen weak La Nina events, six strong La Nina events, twelve weak El Nino events and six strong El Nino events. It was found that there was high rainfall in La Nina events, whereas there was low rainfall in El Nino events. Also, we constructed the corresponding wind circulation and sea level pressure maps in order to better understand the mechanisms associated with this phenomenon that have affected rainfall variability over Thailand.

Keywords: Rainfall over Thailand, EOF, ENSO.

1. Introduction

Thailand has an area of 513,120 square kilometers (198,120 square miles), situated at the southeastern part of the Indochina peninsula, with latitude between 5°N and 20°N and longitude between 97°E and 105°E. So, it is located in the tropics and its climate is primarily influenced by the two prevailing monsoons that are the summer (southwest) monsoon and the winter (northeast) monsoon (TMD, 2007). The southwest monsoon starts in May and brings warm moist air from the Indian Ocean towards Thailand, which is a cause of abundant rain over the country. Rainfall during this period is not only caused by the southwest monsoon but also by the Inter Tropical Convergence Zone (ITCZ) [1-2] and tropical cyclones [3-4], which produce large amounts of rainfall. The first arrival of the ITCZ to the southern part of Thailand is in May. It moves northward rapidly and lies across southern China around June to early July causing a reduction of rainfall over upper Thailand. The ITCZ then moves south and lies over the northern and northeastern parts of Thailand in August and later over the central and southern parts in September and October respectively [5]. The northeast monsoon starts in October and brings cold and dry air from China to Thailand, particularly over the northern and northeastern parts, whereas there is rainfall in the southern part of Thailand [6-7].

The El Nino Southern Oscillation (ENSO) is an ocean-atmosphere phenomenon of the Pacific Ocean with a semi-periodic multi-annual cycle [8-9]. It mainly exhibits a 2-7 years variation, which is characterized by the warming (El Nino) and cooling (La Nina) sea surface temperature (SST) anomalies in the eastern and central equatorial Pacific [10-11]. There are a number of studies showing the influence of ENSO on the climate over the East Asian and the Indochina regions [12-15]. The association between ENSO and the northeast monsoon affects rainfall amount in the southern part of the Indochina Peninsula [13].

A study of the influence of the Asian summer monsoon on Thailand rainfall using the analysis of rain-gauge data during June to September [16] shows that the rainfall annual cycle is in phase with the Indian summer monsoon (ISM) and the western North Pacific summer monsoon (WNPSM). Another study [17] shows some relationships between the large-scale climate features and the summer monsoon precipitation over the central and northern regions of Thailand. It was found that the eastern Pacific sea surface temperatures in ENSO have a negative relationship with the summer monsoon rainfall over Thailand. Most of the previous studies focused on climate features resulting from the rainfall in Thailand, but they did not analyze the rainfall variability and describe the mechanism related to the variability.

Therefore, this research aims to analyze the rainfall variability of Thailand by using the Empirical Orthogonal Function (EOF) analysis. We also discuss the mechanism of large scale features and the ENSO forcing that influence the rainfall variability at the country scale.

2. Experimental

This study applied the monthly rainfall data of the full data reanalysis product version 6 from the Global Precipitation Climatology Centre (GPCC), in a horizontal resolution of 0.5°×0.5° latitude and longitude, for 1971 to 2010 [18]. GPCC provides gridded gauge-analysis products for the earth's land surface derived from quality controlled station data. We have used the rainfall data over the Thailand region (5.5°N - 21°N, 97.5°E - 106°E) to analyze the spatial and temporal pattern by EOF analysis.

The EOF analysis is a useful technique in meteorology and oceanography for descriptive multivariate statistics. It is based on a representation of the large data sets in terms of a limited number of orthogonal basis functions while retaining as much as possible of the variations in the data. In the EOF technique the data are first arranged into a matrix $\mathbf{Z} = \left[z_{tx} \right]_{n\times p}$, where z_{tx} is the rainfall amount collected at the time t ($t = 1, 2, 3, ..., n$) and station x ($x = 1, 2, 3, ..., p$). Before the analysis the anomaly data matrix is prepared as

$$\mathbf{Z}' = \mathbf{Z} - \overline{\mathbf{Z}}, \tag{1}$$

where $\mathbf{Z}$ is the rainfall data, $\overline{\mathbf{Z}}$ is the rainfall mean (climatology) and $\mathbf{Z}'$ is the rainfall anomaly. Next, we determined the covariance matrix $\mathbf{R}$ as follows

$$\mathbf{R} = \frac{1}{n-1}\mathbf{Z}'^{\mathrm{T}}\mathbf{Z}', \tag{2}$$

where $\mathbf{R}$ is a symmetric $p \times p$ matrix and $\mathbf{Z}'^{T}$ is the $p \times n$ transpose matrix of $\mathbf{Z}'$.

The EOF analysis uses this covariance matrix to decompose the space-time data into spatial patterns and associated time indices [19-20]. The eigenvalues of the covariance matrix are given by

$$\mathbf{RE}_i = \mathbf{E}_i \lambda_i ; \quad i = 1, \ldots, P, \tag{3}$$

where $\mathbf{E}_i$ is the i^{th} eigenvector and λ_i is the i^{th} eigenvalue.

The principal component time series can be derived by projecting the original data series $\mathbf{Z}'$ onto the eigenvectors $\mathbf{E}$ as follows

$$\mathbf{A} = \mathbf{Z}'\mathbf{E}, \tag{4}$$

where $\mathbf{A}$ is the $n \times p$ principal component matrix showing the time series of coefficients of each EOF mode in the time series of anomalies. The elements of $\mathbf{A}$ are called the principal components (PC) of the analysis.

The National Centers for Environmental Prediction – National Center for Atmospheric Research (NCEP-NCAR) global atmospheric reanalysis data [21] also yielded zonal and meridional winds (u, v) at 850 hPa and the Sea Level Pressure (SLP) on a 2.5°×2.5° global grid. The relation between these data and ENSO has been investigated in this study.

3. RESULTS

3.1 Rainfall variability over Thailand

In this study it was found that the most dominant mode in the EOF analysis of the monthly rainfall anomalies over Thailand during 1971 to 2010 accounts for 21.6% of the total variance. Figure 1(a) shows the spatial pattern of the most dominant mode, and figure 1(b) shows the temporal variation of this mode. Since the values in the spatial pattern are strongly positive over most of Thailand, it follows that when the principal component (PC) in the time series is positive most of Thailand has higher than normal rainfall, and when the PC is negative most of Thailand has lower than normal rainfall. An exception to this result occurs in southern Thailand at latitudes below 9°N where the spatial pattern of the most dominant mode is only weakly positive.

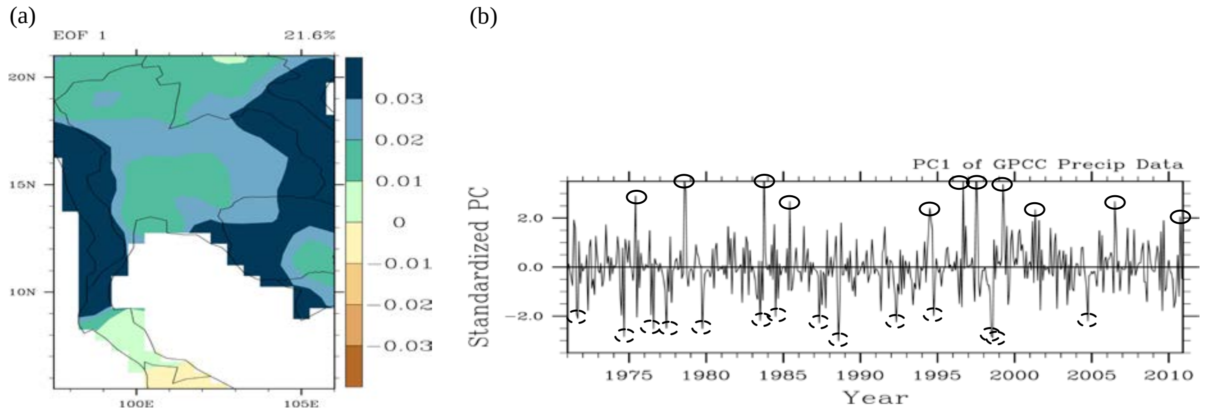

Figure 1. The EOF results of (a) the eigenvector and (b) the principal component time series of the first mode of GPCC data over Thailand during 1971 to 2010.

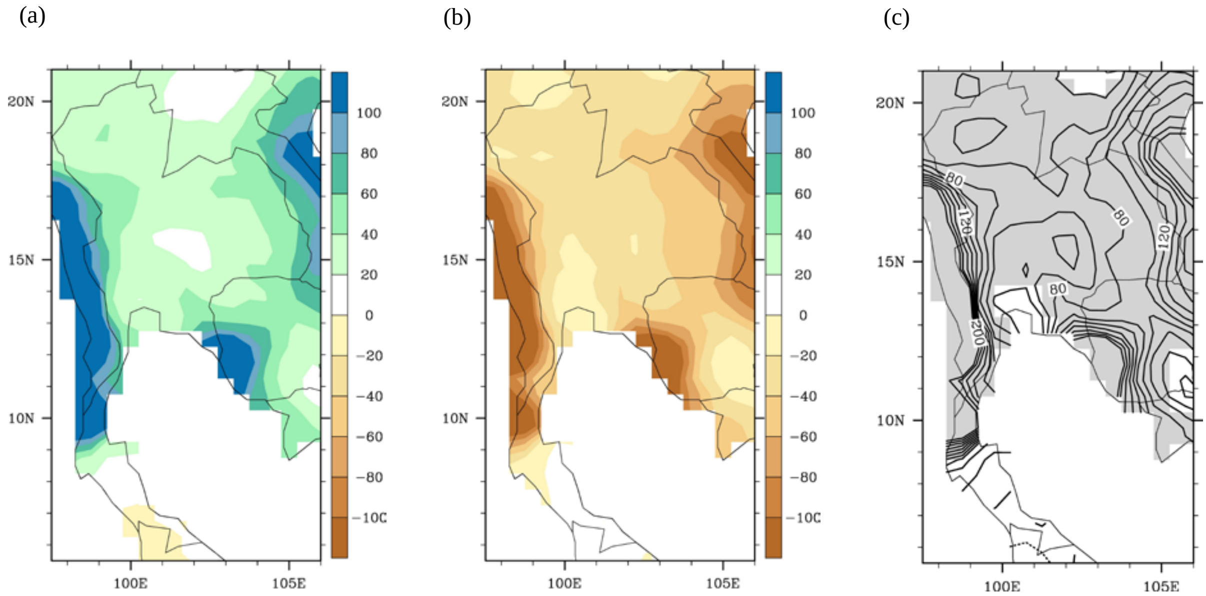

Figure 2. The average rainfall anomalies (mm/month) over Thailand for (a) positive standardized PC, (b) negative standardized PC, and (c) difference between (a) and (b) during 1971 to 2010. The contour interval is 20 mm/month and the shading shows where the difference is significant at the 95% level as determined by Student's *t* test.

When studying the relation between the eigenvector and principal component, it was found that there was high rainfall (standardized PC greater than 2.0) in June 1975, August 1978, October 1983, June 1985, July 1994, September 1996, July 1997, April 1999, May 2001, July 2006 and October 2010. On the contrary, there was low rainfall (standardized PC less than −2.0) in September 1971, September 1974, August 1976, June 1977, October 1979, July 1983, July 1984, May 1987, August 1988, May 1992, October 1994, July 1998, August 1998 and October 2004 (see small circles in figure 1(b)).

To verify our rainfall analysis using the EOF method we show in figure 2(a) the average rainfall anomaly map (mm/month) over all the months with positive standardized PC during 1971 to 2010, and in figure 2(b) the map averaged over all the months with negative standardized PC. It was found that there was greater than average rainfall almost everywhere in figure 2(a) and less than average rainfall almost everywhere in figure 2(b). Figure 2(c) shows the difference between the average anomalies in figure 2(a) and 2(b) with contour interval 20 mm/month. The shaded region, covering most of the study area shows where the difference is significant at the 95% confidence level by Student's *t*-test.

3.2 Teleconnection to ENSO

Many researchers have studied the response of the atmosphere to ENSO [22-24]. Teleconnections between the tropical Pacific and the remainder of the globe have been found in numerous observational analyses [25-26]. Because Thailand lies between the equatorial Indo-Pacific basins, the rainfall variability over Thailand is linked to ENSO. This section reports our study of this relationship.

The Nino 3.4 SST index is the 5-month running mean of sea surface temperature anomalies (°C) in the Nino 3.4 region (5°N - 5°S, 120°W - 170°W) [27]. We determined the correlation between this index and our standardized principal component smoothed using a 5-term low-pass Lanczos filter [28]. Figure 3 shows time series plots of these quantities. The correlation coefficient between them is −0.1651. It is negative, because a high SST anomaly gives a low rainfall anomaly, and a low SST anomaly gives a high rainfall anomaly.

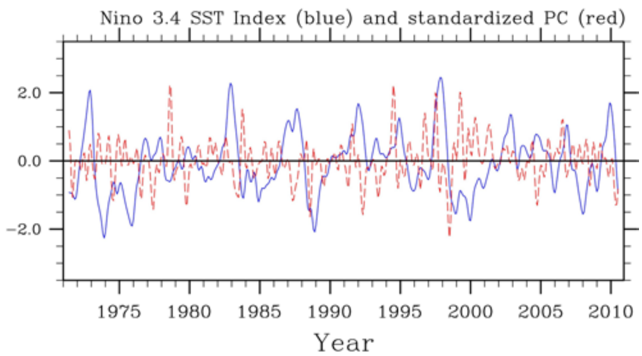

Figure 3. Time series plots of the Nino region 3.4 SST index (blue) and the standardized smoothed principal component using a 5-term Lanczos filter (red).

The time series of the Nino 3.4 SST index values during the period of our study is shown in figure 4. We classify the ENSO events as weak or strong following Bulic and Brancovic [29]. The weak ENSO refers to the Nino 3.4 index from 1.0°C to 1.5°C, and the strong ENSO refers to the Nino 3.4 index larger than 1.5°C. Our analysis is based on composites of fourteen weak La Nina events, six strong La Nina events, twelve weak El Nino events and six strong El Nino events as shown in figure 4 and table 2.

The correlations between the Nino 3.4 SST index and smoothed standardized PC index at various lag times are shown in table 1. The highest correlation of −0.3106 indicates that the Nino 3.4 SST index leads the standardized PC values by 4 months.

Table 1. The correlation between the Nino 3.4 SST index and the standardized PC at various lag times.

Lag time (months)	Correlation coefficient
0	−0.1651
1	−0.2037
2	−0.2436
3	−0.2843
4	−0.3106
5	−0.3060
6	−0.2679

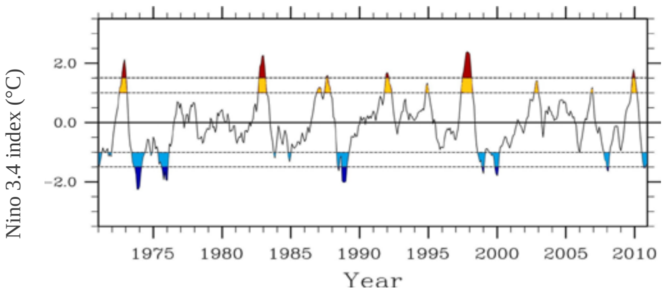

Figure 4. Nino 3.4 SST anomaly index for the period 1971-2010.

Table 2. Years in the period 1971-2010 in the SST categories of ENSO events.

SST category	Number of years	Years
Strong La Nina	6	1973, 1975, 1988, 1999, 2000, 2008
Weak La Nina	14	1971, 1974, 1975, 1976, 1983, 1984, 1988,1989, 1998, 1999, 2000, 2007, 2008, 2010
Weak El Nino	12	1972, 1982, 1983, 1987, 1991, 1992, 1994, 1997, 1998, 2002, 2006, 2010
Strong El Nino	6	1972, 1982, 1987, 1992, 1997, 2009

The composite averages of rainfall anomalies over Thailand for weak-ENSO periods, strong-ENSO periods and their differences are presented in figure 5. There was high rainfall in the cold phase (La Nina) [30] especially in the southern part of Thailand during the weak and strong periods, as shown in figures 5(a) and 5(b). There was low rainfall in the warm phase (El Nino) [30] especially in the southern part of Thailand during the weak and strong periods, as shown in figures 5(c) and 5(d). The differences between the La Nina and El Nino rainfall anomalies during the weak and strong periods are shown in figures 5(e) and 5(f). These differences were higher during the weak-ENSO periods than during the strong-ENSO periods.

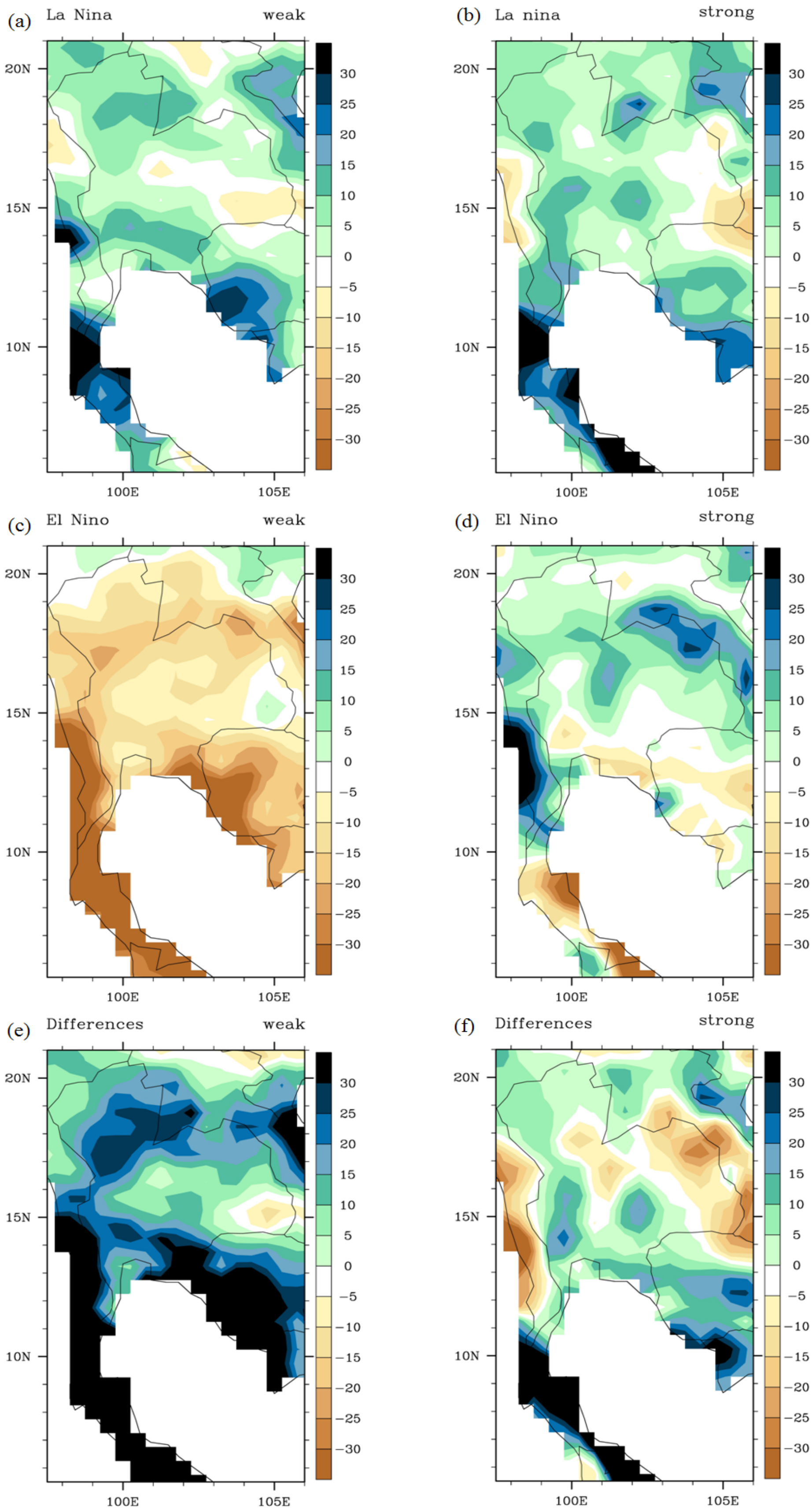

Figure 5. Composite rainfall anomalies (mm per month) for El Nino events and La Nina events over the period 1971 to 2010 and their differences during the weak-ENSO periods, (a), (c) and (e), and the strong-ENSO periods, (b), (d) and (f).

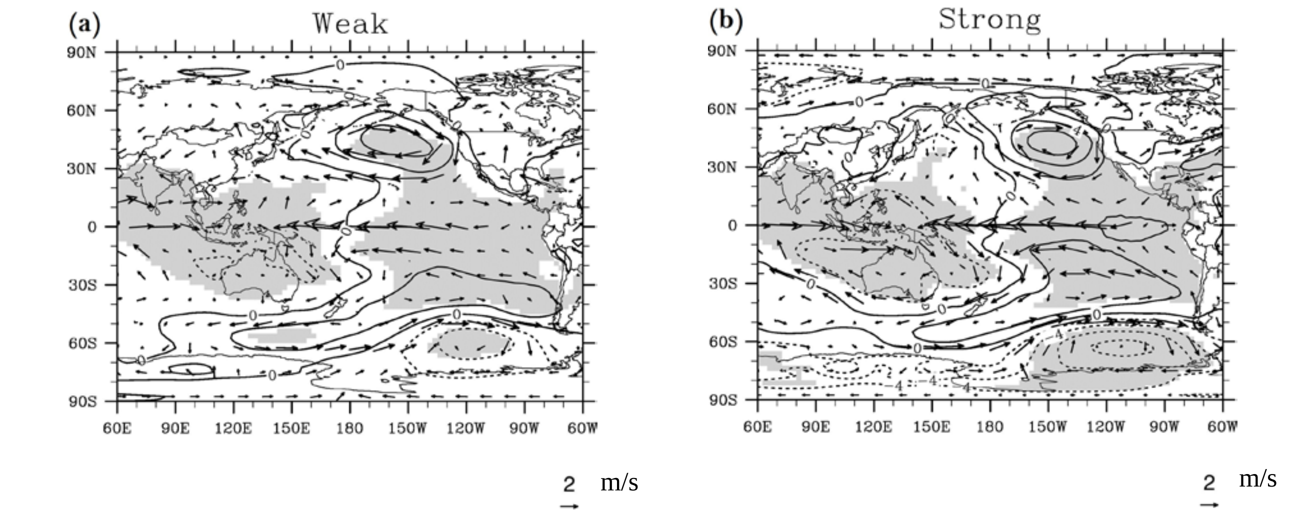

Figure 6. Composite maps of the differences between the La Nina and El Nino wind anomalies at the 850 hPa level and the sea level pressure anomalies for the (a) weak-ENSO periods and (b) strong-ENSO periods from 1971 to 2010. The contour interval for the sea level pressure differences is 2 hPa. Continuous contours are zero and positive; dashed contours are negative. The shaded region shows where the sea level pressure anomaly differences are significant at the 95% confidence level by the Student's *t*-test.

To understand the relationship between rainfall and ENSO, we constructed the corresponding composite wind circulation and the sea level pressure maps. Figure 6 shows the composite maps of the differences between the La Nina and El Nino wind anomalies at the 850 hPa level and the differences between the La Nina and El Nino sea level pressure anomalies for the weak and strong ENSO periods. The region to the west of the Pacific Ocean, including Thailand, Burma, India, Laos, Cambodia, Vietnam and the southern part of China had negative differences between the La Nina and El Nino sea level pressure anomalies in both the weak and strong ENSO periods. This indicates lower pressures in Southeast Asia during the La Nina events than during the El Nino events. The figure also shows that the northern Pacific high has a positive anomaly difference, so the high is intensified during the La Nina events and weakened during the El Nino events. The wind from the east into Southeast Asia is then strengthened during the La Nina and weakened during the El Nino events, as shown by the wind anomaly differences in figure 6. Interaction of these easterly winds from the Pacific with the south-westerly flow from the Indian Ocean then produce stronger than normal convergence and rainfall in Southeast Asia during the La Nina events, and reduced rainfall during the El Nino events.

4. Conclusions

The main results found in this study may be summarized as follows. In our EOF analysis of rainfall over Thailand during the period 1971-2010 the most dominant mode, accounting for 21.6% of the total variance, had a spatial pattern with the same sign (positive) over almost all of Thailand. Consequently, when the PC was positive there was more rainfall than normal and when the PC was negative there was less rainfall than normal almost everywhere. An exception to this general result occurs in the south at latitudes below 9°N.

In our study of the teleconnection between rainfall over Thailand and ENSO it was found that the differences between the La Nina and El Nino rainfall anomalies were higher during the weak-ENSO periods than during the strong-ENSO periods. A possible explanation for this is that there were twice as many weak-ENSO events as strong-ENSO events.

Our maps of the 850 hPa wind and sea level pressure anomalies showed that the wind from the east is strengthened during the La Nina events producing more than normal rainfall in Southeast Asia, and is weakened during the El Nino events producing less than normal rainfall in Southeast Asia.

Acknowledgements

The authors wish to acknowledge the Global Precipitation Climatology Centre (GPCC) for the data set and the developer of the NCAR Command Language (NCL) for analysis and graphic visualization tool. Finally, the authors sincerely thank the Joint Graduate School of Energy and Environment (JGSEE) and the Centre of Excellence on Energy Technology and Environment (CEE), Science and Technology Postgraduate Education, Research Development Office (PERDO) and Thailand Research Fund (TRF) under the grant: RDG5630015 for study support.

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